Exposure to Tetrachloroethylene in Dry Cleaning Shops in the Nordic Countries

ELSEBETH LYNGE1*, HÅKAN TINNERBERG2, LARS RYLANDER2, PAL ROMUNDSTAD3, KRISTINA JOHANSEN1, MARJALISA LINDBOHM4, PIRJO HEIKKILÄ4, HÅKAN WESTBERG5, LENE BJØRK CLAUSEN1, ANTOINE PIOMBINO1 and BRIAN LARSEN THORSTED1

1Institute of Public Health, University of Copenhagen, Øster Farimagsgade 5, DK-1014 København K, Denmark; 2Division of Occupational and Environmental Medicine and Psychiatric Epidemiology, Lund University Hospital, SE-221 00 Lund, Sweden; 3Department of Community Medicine and General Practice, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway; 4Finnish Institute of Occupational Health, FI-00250 Helsinki, Finland; 5Department of Occupational and Environmental Medicine, Örebro University Hospital, SE-701 85 Örebro, Sweden

Received 28 January 2010; in final form 1 December 2010; published online 3 February 2011

Objectives: Tetrachloroethylene is the dominant solvent used in dry cleaning worldwide and many workers are potentially exposed. We report here on results of 1296 measurements of tetrachloroethylene undertaken in Nordic dry cleaning shops 1947–2001.

Methods: We searched documents and files in the Nordic institutes of occupational health for air measurements of tetrachloroethylene. Repeated measurements from the same facility during a short time interval were registered only once using the time-weighted average. We registered also changes over time in occupational exposure limits (OELs) to tetrachloroethylene.

Results: Only scattered measurements were available from the early years, and the exposure level seemed fairly stable up until the mid 1970s. The median exposure level was 20 p.p.m. in 1976 and decreased to 3 p.p.m. in 2000. Exposure levels in the four Nordic countries followed similar trends. In the late 1960s, the OELs varied between the Nordic countries from 30 to 100 p.p.m. Sweden was first to lower the limit, but limits gradually converged over time. At present, Denmark, Finland, and Sweden use 10 p.p.m., while Norway uses 6 p.p.m. Over time, the average observed exposure level was lower than the OEL in all countries, but in Denmark and Sweden, up to one-third of measured exposures exceeded the OEL. Overall, the stationary measurements for maintenance work showed 36 p.p.m., while the personal measurements showed 7.5 p.p.m. for dry cleaners and 6.25 p.p.m. for shop assistants.

Conclusion: The Nordic data illustrate that it is possible over time to control chemical exposures even in an industry consisting of many small and scattered work places.

Keywords: dry cleaning; exposure assessment; tetrachloroethylene

INTRODUCTION

In the early 1960s, the non-flammable tetrachloroethylene, CAS 127-18-4, substituted the highly flam-

*Author to whom correspondence should be addressed.
Tel: +45-35-32-76-35; fax: +45-35-32-73-83; e-mail: elsebeth@pubhealth.ku.dk

mable Stoddard solvent as the predominantly used dry cleaning solvent in the USA and Europe. This was from a safety point of view a major improvement. However, as the awareness of the potential neurotoxicity of the chlorinated solvents emerged in the 1970s, tetrachloroethylene started to be replaced by chlorofluorocarbons (CFCs). This
development was reversed by the realization of the ozone layer depletion capacity of the CFCs. From the 1990s, tetrachloroethylene is therefore back as the main solvent in dry cleaning. Use of tetrachloroethylene is, however, not unproblematic. Within the European Union, the compound is labelled with two risk sentences, ‘limited evidence of a carcinogenic effect’ and ‘toxic to aquatic organisms’, may cause long-term adverse effects in the aquatic environment. The health concern derives from the probable carcinogenicity of tetrachloroethylene based on the occurrence of liver cancer in exposed mice and on limited evidence for oesophageal cancer, cervical cancer, and non-Hodgkin’s lymphoma in exposed workers (International Agency for Research on Cancer, 1995). Epidemiological studies have also raised concern about a possible risk of spontaneous abortions among women working in dry cleaning (Kyrönen et al., 1989; Doyle et al., 1997), as well of detrimental health effects in offspring of tetrachloroethylene-exposed persons (Perrin et al., 2007; Aschengrau et al., 2009).

In 1995, the internationally available data indicated that the average exposure level to tetrachloroethylene in dry cleaning shops decreased from 50–100 p.p.m. in the 1970s to 10–50 p.p.m. in the 1980s (International Agency for Research on Cancer, 1995). A review from 2008 based on measurements reported in the international literature and in the National Institute for Occupational Safety and Health (NIOSH), Health Hazard Evaluation database from 1936 to 2001 found the mean exposure level in the dry cleaning industry to have been 57 p.p.m. (Gold et al., 2008). We undertook a case–control study on cancer in dry cleaners from the Nordic countries (Lynge et al., 2006). As part of the background material for this study, we assembled a database on all tetrachloroethylene air measurements undertaken in dry cleaning facilities in Denmark, Finland, Norway, and Sweden from 1947 to 2001. This database has enabled us to map the exposure level to tetrachloroethylene in dry cleaning in the Nordic countries over an almost 50-years period. These historical exposure data are useful for two purposes. Firstly, they should be used in the design of epidemiological studies addressing the potential health effects of exposure to tetrachloroethylene. Secondly, they should be used in evaluation of the relevance of existing epidemiological data for the working conditions in the dry cleaning industry today.

MATERIALS AND METHODS

Data collection

We aimed at collecting information on all air measurements of tetrachloroethylene undertaken in dry cleaning facilities in the Nordic countries up until 2000. From Denmark, data on all measurements undertaken for the labour inspection from 1947 to 1987 are stored in the National Institute of Occupational Health, and these data were retrieved for the present study. After this point in time, measurements may be stored in archives of local monitoring companies, but few such measurements are supposed to have been made.

In Finland, the Finnish Institute of Occupational Health has carried out chemical exposure surveys since the 1950s. Information on measurements is stored in the Finnish database of occupational exposure measurements (FDOEM) (Heikkilä et al., 2005). All registered measurements of tetrachloroethylene air concentration in dry cleaning shops registered in FDOEM were compiled. They covered the period from 1956 to 1999. In addition to these measurements undertaken by request from the companies, a summarized exposure estimate was taken from a study carried out by the Finnish Institute of Occupational Health (Räisänen et al., 1998).

In Norway, all measurements were retrieved from the National Institute of Occupational Health and covered the period from 1976 to 2001, from the period before 1985 from published reports (Lillesand and Hag, 1984), and from 1985 onwards from the National Institute of Occupational Health’s exposure database EXPO (Rajan et al., 1997).

In Sweden, the samples were collected between 1973 and 1995. Most of the measurements were retrieved from the archives in the Swedish work environment authority. The measurements were mainly undertaken in campaigns during 1977, performed by the Swedish Environmental Research Institute, during 1979–1984 by the work inspectorate, and between 1988 and 1989 in a project performed by the Department of Occupational and Environmental Medicine in Örebro.

Up until 1977, almost only stationary air measurements were undertaken, where after also measurements in the breathing zone of the workers were introduced. Information about the sampling technique and analytical method was not recorded. However, as for air measurements of trichloroethylene, absorption in ethanol dominated up to 1973, where the use of charcoal tubes took over (Raaschou-Nielsen et al., 2002).
It should be noted that although both shop and person identity were known in the original documents, this information was not entered in the Nordic data set. It was therefore not possible to analyse variation in exposure level across shops, it was neither possible to analyse variation between persons within a given shop. The job titles included in the present data set come from the registered work tasks for personal measurements and the registered work areas for stationary measurements. It was therefore not possible from the data set to see if a person measured while undertaking dry cleaning, and consequently analysed as a ‘dry cleaner’, worked as a shop assistant at other times. Registered variables are listed in Table 1. We furthermore collected information on the occupational exposure limits (OELs), for tetrachloroethylene over time in each of the four countries.

Analysis

The original documents included many repeated measurements from the same facility during a short time interval, e.g. on a single day. Such measurements are by definition highly correlated. Repeated measurements from the same person or repeated measurements from the same work area were therefore registered as a single measurement entering the entire number of measurement hours/minutes and the time-weighted average concentration in the database. Data from different persons working in the same shop and/or from different work areas in the same shop were not aggregated.

Our main purpose was to assess the overall trend in tetrachloroethylene exposure level in the dry cleaning industry. For the four countries together and for each country separately, we plotted all measured concentrations by year of measurement. All measurements were included in this analysis independently of whether they were stationary or personal measurements. As repeated measurements from the same person/same work area were not registered individually, we did not know the variance, and we therefore made a relatively simple analysis of the time trends. For each year, we used the median of the observations, and a 95% confidence interval

Table 1. Information collected on air measurements of tetrachloroethylene in dry cleaning facilities in the Nordic countries 1947–2001

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>Denmark</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>Finland</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>426</td>
</tr>
<tr>
<td></td>
<td>Sweden</td>
<td>658</td>
</tr>
<tr>
<td>Year of sampling</td>
<td>1947–2001</td>
<td>See Table 2</td>
</tr>
<tr>
<td>Reason for sampling</td>
<td>Inspection</td>
<td>463</td>
</tr>
<tr>
<td></td>
<td>Assess patient exposure</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Project</td>
<td>536</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>168</td>
</tr>
<tr>
<td>Work task (personal sampling)/work area (stationary sampling)</td>
<td>Dry cleaner</td>
<td>770</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>280</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>132</td>
</tr>
<tr>
<td>Type of sampling</td>
<td>Stationary</td>
<td>609</td>
</tr>
<tr>
<td></td>
<td>Personal</td>
<td>687</td>
</tr>
<tr>
<td>Length of sampling</td>
<td>Measured in minutes</td>
<td></td>
</tr>
<tr>
<td>Tetrachloroethylene concentration</td>
<td>Measured in p.p.m.</td>
<td></td>
</tr>
<tr>
<td>Size and lay out of work area</td>
<td>NA*</td>
<td></td>
</tr>
<tr>
<td>Number of workers in work area</td>
<td>NA*</td>
<td></td>
</tr>
<tr>
<td>Number and type of dry cleaning machines</td>
<td>NA*</td>
<td></td>
</tr>
<tr>
<td>Sampling technique</td>
<td>NA*</td>
<td></td>
</tr>
</tbody>
</table>

NA = not available.

*Data available only in non-standardized form in free text were not entered in the database. Assessment of patient exposure was sometimes undertaken as part of a worker compensation case.
(CI) for the median was estimated using bootstrap
(Efron, 1987). Exposure level by work task/work
area, type of sampling, and reason for sampling were
estimated by the median and bootstrapped 95% CIs
for the four countries together and for each country
separately. SAS version 9.2 (SAS Institute Inc.)
and R (R version 2.10.0, 2009) were used for the
analysis.

RESULTS

A total of 1296 measurements were registered: 86
from Denmark, 126 from Finland, 426 from Norway,
and 658 from Sweden (Table 2). Measurements from
the four countries were very unequally distributed by
year of sampling. Basically, no measurements were
available from Norway and Sweden before 1975,
and all Danish measurements were made before
1990.

The samples were equally divided between per-
sonal samples (687/1296) and stationary samples
(609/1296). In total, 66% of the measurements had
a sampling length of at least 1 h, and 66% of the
measurements were undertaken in the cleaning area
(Table 3).

The tetrachloroethylene concentrations by country
and year showed a wide variation. In 1969, the mea-
sured level varied for instance from 1 to 637 p.p.m.
In 1990, a range from 1 to 203 p.p.m. was found.
Based on the sparse measurements, the trend in the
median exposure level was stable from 1947 to
1976, where after a fairly steadily downward trend
was observed from a median of 19.59 p.p.m. (95%
CI 13.33–34.81 p.p.m.) in 1976 to a median of
2.61 p.p.m. (95% CI 0.53–3.16 p.p.m.) in 2000
(Fig. 1A). Personal measurements were available only
from 1969 onwards, with a time trend fairly similar
to that found for all measurements (Fig. 1B).

The OELs for tetrachloroethylene decreased over-
time in all four countries. The Danish limit was first
set to 50 p.p.m. in 1957 and it remained at this level
up until 1975 where it decreased to 30 p.p.m.
(Sikkerhedsudvalget for Kemiske Industrier, 1973),
and in 1995, it was lowered again to the present level
of 10 p.p.m. (Arbejdstilsynet, 2005). Finland had
a very high limit value of 200 p.p.m. before 1962
(Sosiaaliministerion, 1960), where it was decreased
to 100 p.p.m. (Sosiaaliministerion, 1962). The Fin-
ish limit was decreased again in 1972 to 50 p.p.m.
(Sosiaali- ja terveysministerion, 1972), but it contin-
tued to be above the level for the other Nordic coun-
tries up until 2000 where it was set to 10 p.p.m.
(Sosiaali- ja terveysministerio, 2000). Before 1978,
the Norwegian limits were based on the American
Conference of Governmental Industrial Hygienist’s
(ACGIH’s) list (ACGIH, 2006), being 100 p.p.m.
up to 1978. In 1978, the Norwegian limit was set
to 30 p.p.m.; it was lowered to 20 p.p.m. in 1989,
and it was further/reduced to 6 p.p.m. in 2001
(Arbeidstilsynet.no, 2003), the so far lowest level
seen in the Nordic countries. Sweden started out with
a recommended limit of 30 p.p.m. already in 1969
(Arbetsmedicinska institutet, 1969), which became
mandatory in 1974 (Arbetarskyddsstyrelsen, 1974).
The limit decreased to 20 p.p.m. in 1978
(Arbetarskyddsstyrelsen, 1978) and again to 10
p.p.m. in 1989 (Arbetarskyddsstyrelsen, 1989).

All four countries had observed exposure levels
with the median exposure level predominantly below
the OELs (Fig. 2). This was in particular the case in
Finland, where the OELs were up until 2000 higher
than in the other Nordic countries. However, 31% of
the measurements in Denmark exceeded the OEL at
the time of measurement, and this was the case for
7% of measurements in Norway, for 12% of meas-
urements in Finland, and for 27% of measurements
in Sweden.

Stationary measurements showed a higher expo-
sure level than personal measurements, overall
11.92 p.p.m. (95% CI 10.66–13.51 p.p.m.) as com-
pared with 7.27 p.p.m. (95% CI 6.78–7.79 p.p.m.).
For stationary measurements, maintenance work
had the highest exposure level 35.94 p.p.m. (95%
CI 20.92–55.99 p.p.m.), followed by dry cleaners
13.20 p.p.m. (95% CI 11.13–15.24 p.p.m.), and shop
assistants 7.50 p.p.m. (95% CI 6.84–8.02 p.p.m.).
This pattern was found in Denmark, Finland, and
Sweden, whereas there was little difference between
the three groups in Norway. For personal

---

Table 2. Number of tetrachloroethylene air measurements in
dry cleaning facilities in the Nordic countries 1947–2001

<table>
<thead>
<tr>
<th>Year–1949</th>
<th>Denmark</th>
<th>Finland</th>
<th>Norway</th>
<th>Sweden</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1945–1949</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1950–1954</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1955–1959</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>1960–1964</td>
<td>48</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>54</td>
</tr>
<tr>
<td>1965–1969</td>
<td>6</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>1970–1974</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1975–1979</td>
<td>11</td>
<td>9</td>
<td>28</td>
<td>97</td>
<td>145</td>
</tr>
<tr>
<td>1980–1984</td>
<td>10</td>
<td>22</td>
<td>36</td>
<td>360</td>
<td>428</td>
</tr>
<tr>
<td>1985–1989</td>
<td>8</td>
<td>23</td>
<td>149</td>
<td>182</td>
<td>362</td>
</tr>
<tr>
<td>1990–1994</td>
<td>0</td>
<td>10</td>
<td>165</td>
<td>17</td>
<td>192</td>
</tr>
<tr>
<td>1995–1999</td>
<td>0</td>
<td>14</td>
<td>47</td>
<td>0</td>
<td>61</td>
</tr>
<tr>
<td>2000–2005</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td>126</td>
<td>426</td>
<td>658</td>
<td>1296</td>
</tr>
</tbody>
</table>
measurements, dry cleaners had an overall exposure level of 7.50 p.p.m. (95% CI 6.73–7.94 p.p.m.) and followed by shop assistants 6.25 p.p.m. (95% CI 4.09–8.93 p.p.m.). The pattern varied considerably across countries. Dry cleaners had a much higher exposure level than shop assistants in Denmark and Finland, whereas the difference was smaller in Sweden, and the two groups were fairly similar in Norway. No personal exposure measurements were available from maintenance workers. Measurements collected as part of patient exposure assessment showed the highest median: 10.32 p.p.m. (95% CI 0.15–19.66 p.p.m.), with all measurements coming from Denmark. Measurements collected as part of inspection showed the same exposure level: 8.00 p.p.m. (95% CI 6.51–9.19 p.p.m.) as measurements.
collected as part of a project: 8.05 p.p.m. (95% CI 6.07–9.10 p.p.m.) Table 4.

DISCUSSION

The available data indicate that a fairly stable exposure level to tetrachloroethylene in dry cleaning shops in the Nordic countries up until the mid 1970s, the median exposure level being 20 p.p.m. in 1976. This level was below the OELs of the Nordic countries at that time, being 30 p.p.m. in Denmark, Norway, and Sweden and 50 p.p.m. in Finland. From 1976 onwards, the measured exposure level decreased reaching 3 p.p.m. in 2000, again well below the OELs, being 10 p.p.m. Denmark, Finland, and Sweden and 6 p.p.m. in Norway. The overall exposure to tetrachloroethylene in the Nordic dry cleaning shops has thus undergone a dramatic development over the last 25 years with a drop in median exposure level of ~17 p.p.m. This result is in line with the outcome of a meta-analysis of ~700 sets of exposure data for various compounds published over a 30 year period, where 78% of the natural log-transformed data showed linear trends towards lower exposure levels (Symanski et al., 1998).

The decreased exposure level reflects the technological developments over time. In Denmark, tetrachloroethylene-based semi-automated dry cleaning machines where the clothes could be both dry cleaned and dried were available already in the 1950s. In 1959, the fully automated German ‘Zanker’ and the English ‘Spencer’ machines

Fig. 2. Observed air measurements of tetrachloroethylene in dry cleaning 1947–2001, median, and OEL to tetrachloroethylene for Denmark, Finland, Norway, and Sweden.
Table 4. Median of tetrachloroethylene air measurements in dry cleaning facilities in the Nordic countries 1947–2001 by work task/work area and measurement type together with bootstrapped 95% CIs

| Country | Measurement type: stationary | | Measurement type: personal | |
|---------|-----------------------------|---|---|---|---|---|---|---|---|
|         | Work task/work area         | | | | | | | |
|         | Dry cleaner | Shop assistant | Maintenance | Unknown¹ | Total | Dry cleaner | Shop assistant | Maintenance | Unknown¹ | Total |
| All     | N | 309 | 176 | 108 | 16 | 609 | 461 | 104 | — | 122 | 687 |
|         | Median | 13.20 | 7.50 | 35.94 | 2.65 | 11.92 | 7.50 | 6.25 | — | 4.00 | 7.27 |
| Denmark | N | 32 | 6 | 29 | — | 67 | 9 | 10 | — | — | 19 |
|         | Median | 11.99 | 4.72 | 50.87 | — | 18.17 | 22.97 | 3.41 | — | — | 10.32 |
|         | 95% CI | 5.34–17.12 | 3.13–6.04 | 31.23–71.58 | — | 8.93–26.44 | 2.61–41.23 | −10.10 to 13.29 | — | — | −4.85 to 23.41 |
| Finland | N | 61 | 10 | 17 | 2 | 90 | 32 | 4 | — | — | 36 |
|         | Median | 12.35 | 9.81 | 74.13 | 4.51 | 15.84 | 5.31 | 0.21 | — | — | 4.87 |
|         | 95% CI | 6.61–18.90 | 2.06–18.54 | 3.31–118.97 | −2.62 to 11.64 | 11.63–21.55 | 2.10–8.23 | −10.06 to 6.45 | — | — | 1.83–7.73 |
| Norway  | N | 106 | 33 | 30 | 13 | 182 | 125 | 40 | — | 79 | 244 |
|         | Median | 12.25 | 13.00 | 11.50 | 2.40 | 11.45 | 3.42 | 3.66 | — | 2.70 | 3.20 |
|         | 95% CI | 9.43–15.60 | 11.35–15.05 | 5.95–16.35 | −1.11 to 5.06 | 9.44–13.42 | 1.94–4.67 | −0.85 to 6.87 | — | 1.68–3.40 | 2.48–3.83 |
| Sweden  | N | 110 | 127 | 32 | 1 | 270 | 295 | 50 | — | 43 | 388 |
|         | Median | 15.00 | 7.50 | 38.00 | 3.20 | 10.00 | 9.00 | 7.00 | — | 8.00 | 8.72 |

¹Including six measurement from other work areas.
became available, where better centrifugation meant that less solvent was left in the clothes. From 1964 onwards, dry cleaning was permitted only in automated dry-to-dry machines, which could not start before the doors were closed and the ventilation started. In 1978, the first closed circuit machine was introduced, and this non-vented dry-to-dry machine with a refrigerated condenser was only opened to the atmosphere when the machine door was opened, which further decreased the solvent emission (Johansen et al., 2005). In the mid 1970s, Sweden experienced an intense debate on adverse health effects of exposure to chlorinated organic solvents (Axelson et al., 1976). This led to a lowering of the OEL for tetrachloroethylene, measurement campaigns in several Swedish districts, and instructions for better maintenance of dry cleaning machines. As a result of the close collaboration between the Nordic labour inspections, similar measures were taken in the other Nordic countries.

The exposure level to tetrachloroethylene in the Nordic dry cleaning shops in the 1970s was below the internationally reported level (Gold et al., 2008). Where the mean of the Nordic measurements from 1970 to 1979 was 36 p.p.m. for personal measurements and 25 p.p.m. for stationary measurements, these levels were 67 and 30 p.p.m., respectively, in the review based on international literature and NIOSH measurements primarily (Gold et al., 2008). A possible explanation for the difference might be an early introduction of the dry-to-dry machines in the Nordic countries. While open transfer dry cleaning machines had been prohibited in Denmark since 1953 (Johansen et al., 2005), these machines were still used in one-third of the dry cleaning plants in the USA in 1971 (Mundt et al., 2003). In the 1980s, the mean Nordic exposure levels were 15 p.p.m. for personal and 20 p.p.m. for stationary measurements compared with 31 and 223 p.p.m., respectively, in the US data, the latter though based on very few measurements. In the 1990s, the mean Nordic exposure levels were 6 p.p.m. for personal and 12 p.p.m. for stationary measurements compared with 10 and 84 p.p.m., respectively, in the US data.

Archive measurements as those analysed here, and in most other exposure data sets (Kromhaut and Vermeulen, 2000), do not represent a random sample of the exposure situation in the industry. Measurements may be requested where suspicion arouses, they may be part of a campaign, or they may be undertaken to control the effect of changes at the work place. There was, however, no difference in the exposure level for measurements undertaken for inspection or as part of a project, though stationary measurements, often undertaken to control for leaks in gaskets, showed a higher level than personal measurements. Exposure furthermore varied across job task/work area with a hierarchy going from maintenance work—where only stationary measurements were available—to dry cleaners and to shop assistants. In the interpretation of these observed differences, it should be taken into account that we were not able to control for the variation coming from differences between shops and from differences between persons within a given shop as identity codes for shops and persons were not included in the Nordic data set. In Denmark and Norway, data from controls selected for a case–control study based on employment in 1970 (Lynge et al., 2006) showed that two-thirds of workers in dry cleaning shops were dry cleaners, one-third were assistants and none of the employees in dry cleaning shops was registered as maintenance worker. A similar statistics cannot be made for Finland and Sweden due to many workers with unknown work task (Lynge et al., 2006). The maintenance measurements in the data set were all stationary measurements.

The tetrachloroethylene OELs varied across the Nordic countries in the late 1960s being more than three times higher in Finland than in Sweden. These differences have disappeared and Denmark, Finland, and Sweden now have limits at 10 p.p.m. and Norway has a limit of 6 p.p.m. The Nordic OELs are considerably lower than the present ones in UK, France, Austria, and Switzerland of 50 p.p.m. and in Belgium and Spain of 25 p.p.m. (Bgia-online.hvbg.de, 2010). Among the Nordic countries, Sweden was up until very recently the first country to lower the limit, indicating that Sweden was the driving force in improving the legal work place requirement. The fact that the actual exposure levels in Denmark, Finland, Norway, and Sweden followed fairly similar trends despite differences in OELs indicates that the actual exposure levels have been influenced more by the technological and economic possibilities than by the regulatory policy. The dynamic underlying decisions on OELs was addressed in a critical analysis of the ACGIH TLVs, where the authors concluded that new threshold values were poorly correlated with the incidence of adverse effects and strongly correlated with the actual exposure levels at the time (Roach and Rappaport, 1990).

The present OEL of 10 p.p.m. in Denmark, Finland, and Sweden is two orders of magnitude above the ambient air guideline at 100 µg m⁻³ (~0.015 p.p.m.) issued by the New York State Department of Health (2003) and followed for instance in the Danish regulation for allowed tetrachloroethylene
level in rooms neighbouring a dry cleaning facility (Retsinformation.dk, 2010). In addition to the health risks considered for assessment of OELs, the ambient air guidelines take into account human data related to visual tests, reaction time, and attention.

The dry cleaning industry is characterized by many small shops (Johansen et al., 2005). The time trend in the measurements of tetrachloroethylene reported here illustrates that exposure control is possible even under these circumstances. In conclusion, the outcome of 1296 measurements of tetrachloroethylene from the dry cleaning industry in the Nordic countries indicated a decrease in the exposure level from 20 p.p.m. in 1976 to 3 p.p.m. in 2000. Sweden and Denmark were first to lower the OELs for tetrachloroethylene, but Finland and Norway had less measured exposures exceeding their OELs.

**FUNDING**

Halogenated Solvents Industry Alliance, Inc.

**REFERENCES**

ACGIH. (2006) TLVs® and BEIs® based on the documentation of the threshold limit values and biological exposure indices. 7th edn. Cincinnati, OH: American Conference of Governmental Industrial Hygienists Worldwide Signature Publications. Publication #0100Doc.


Rajan B, Alesbury R, Carton B et al. (1997) European proposal for core information for the storage and exchange of...


R version 2.10.0 (2009-10-26) /C211


Sikkerhedsudvalget for Kemiske Industrier. (1973) Kemikalier og sikkerhed. [Chemicals and safety]. Copenhagen, Denmark: Teknisk Forlag. [in Danish].


